Annual Project Summary

DEEP BOREHOLE TENSOR STRAIN MONITORING, NORTHERN CALIFORNIA

NEHRP Grant 98-HQ-GR-1012

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II

seismology, geodesy, borehole geophysics

Project Objectives and Approach

This project provides field observations critical to an understanding of fault processes associated with earthquakes along the San Andreas and Hayward faults. Continuous high precision and high resolution borehole tensor strain data provide an essential complement to long baseline interferometry studies (limited to sampling intervals of weeks), GPS studies, and seismic characterisation of faults.

The project continues a program of maintenance and analysis of deep borehole tensor strain instrumentation initiated at San Juan Bautista in late 1983, expanded by three sites installed in the Parkfield area during December of 1986, by two sites deployed in the San Francisco Bay region in 1992. These instruments consist of a three component plane strain module operating at a strain sensitivity of 10^{-10}. and support data logging systems. As deployed to date they provide data sampling at 30 minute intervals for transmission via satellite for permanent archive purposes. The instruments provided by this project are unique in the program in that they provide

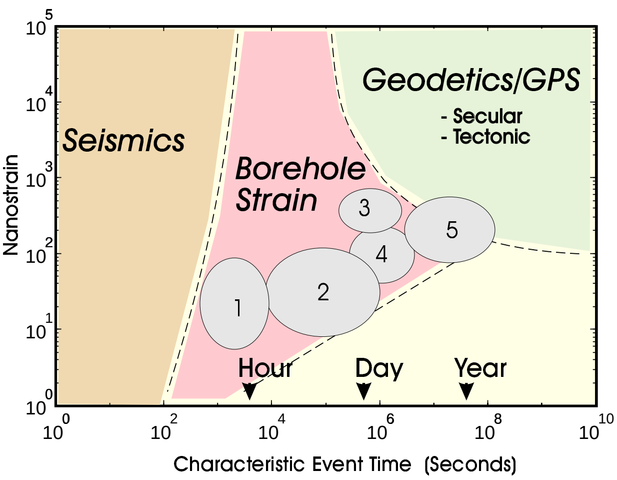

Figure 1. *Effective detection capabilities of seismic,borehole strain, and geodetic instrumentation. The vertical axis is in units of strain, whilst the horizontal axis covers the period band from 1 second to 10^{10} seconds (100 years). GPS instrumentation will lower the boundary of the geodetic domain, but not significantly. For precise monitoring of short term strain rate fluctuations, there is a clear necessity for borehole strain instruments with nanostrain resolution in the minutes - months time scales. Data observed over the past 14 years have included identifiable episodes in the domains shown as 1,..5.*

continuous tensor strain data of high quality and sensitivity not achievable by any other instrumentation. These data form a critical complement to GPS and geodetic studies (see Figure 1) in assessing strain rates and consequent earthquake risk, as well as investigating fault processes associated with earthquake preparation and postseismic relaxation. Data are made available in near real time in the USGS Menlo Park computer system (thebeach:/we/mick/BASEDATA). These data supplement long baseline survey data, and permit real time monitoring for short term strain phenomena.

The **immediate objectives** of the project are

- Maintenance of uphole system integrity at 6 Northern Californian sites, with repair or production of replacement uphole electronics if necessary.
- Manual preparation of raw instrument data for permanent archive.
- Analysis of continuous unique low frequency shear strain data (30 minute samples) and modelling studies based on the constraints of these data
- Regular reporting and real time alert response as part of the Parkfield Prediction experiment.
- Archive of processed data for access by the earthquake studies community, and provision of near-real time automatically processed data for inclusion in publically accessible web pages linked to the USGS web datasets.

The project is carried out in parallel with maintenance of two further sites (Pinon Flat and San Gabriel mountains) in Southern California.

Investigations & Results

San Juan Bautista:

Borehole tensor strain and surface creepmeter observations associated with the mag 5.3 earthquake 10km southeast of San Juan Bautista on August 12 1998 are shown in Figure 2. The aftershock sequence defines a region of the fault approximately 6 km by 8 km at a depth of 5 km which failed seismically during the event (see Figure 3, surface B). The borehole strain data indicate that aseismic strain changes following the event had at least an equivalent magnitude. Aseismic failure of the region (surface C2) immediately above the seismic failure surface is consistent with the observed surface strain and creep, and modelled slip on surface C2 indicates a slow earthquake with equivalent magnitude 5.0 occurred over the 5-10 day period following the seismic events.

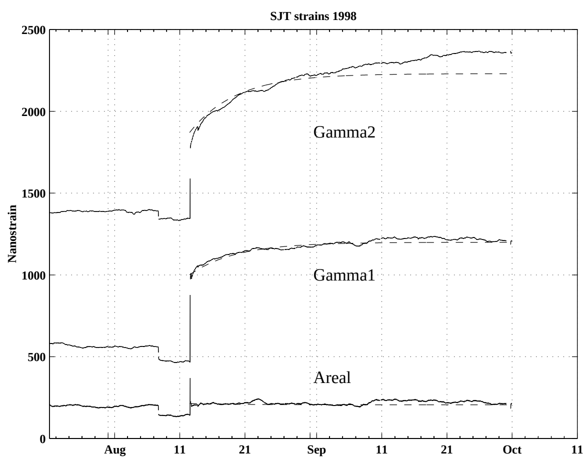

Figure 2. *Strain data oberved near San Juan Bautista during a slow earthquake sequence immediately following a M 5.3 earthquake. Modelled strain resulting from slow slip to the southeast of the site is shown in dotted lines.*

The modelled failure surface of this slow earthquake complement the failure surfaces identified with previous slow earthquakes in December 1992 and April 1996 which were observed at this site, and at the Searle Rd. dilatometer 5 km to the northwest (see Figure 3). These models suggest that the full 20km section of the fault has been relieved to a depth of ~5km over the past 6 years.

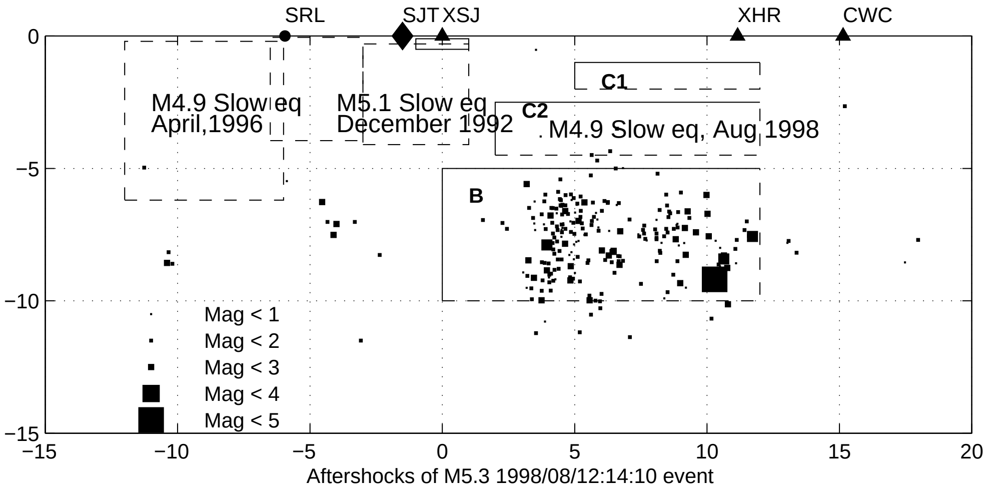

Figure 3. *Mainshock (M 5.3) and aftershock sequence for August 12 1998 San Juan Bautista earthquake. The seismic failure surface is shown as "B", and surfaces C1 and C2 indicate modelled slow slip in the 30 minutes, and 10 days, following the earthquake. Failure surface for two previous slow earthquakes (Dec. 1992 and April 1996) observed at this site are also indicated.*

Long term data from the SJT instrument is shown in Figure 4. The dominant features are the Loma Prieta coseismic offset, slow earthquakes in 1992, 1996 and 1998, 26 episodic strain/creep events (barely distinguishable at the scale of Fig 4), a significant change in shear γ_1 gradient following Loma Prieta, and a significant change in gradient in shear strain γ_2 in 1993.

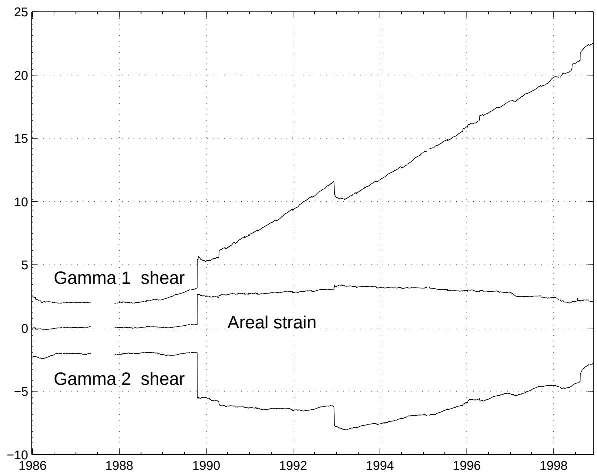

Figure 4. *Long term strain data observed at San Juan Bautista site.*

Parkfield:

The shear strain anomaly identified (*Gwyther et al.*, 1996) in the Parkfield BTSM instruments as commencing in 1993 has continued to date. Data plots of shear strains from each Parkfield instrument (DLT,EDT and FLT) are shown in Figure 5. Data from the DLT instrument is contaminated by an annual hydrological signal caused by a nearby unconfined aquifer. We have processed DLT data to remove the annual hydrological term, and the residual data indicates that a large change in shear strain also occurred at this site in 1993. This strain anomaly has now been independently verified by 2-color laser strain observations (*Langbein*, 1998), and by microearthquake observations of clustered microearthquakes (*Nadeau*, 1998). Modelling studies

(*Roeloffs*, 1997) indicate that the anomaly is most probably not caused by aquifer changes associated with the cessation of drought conditions in 1993.

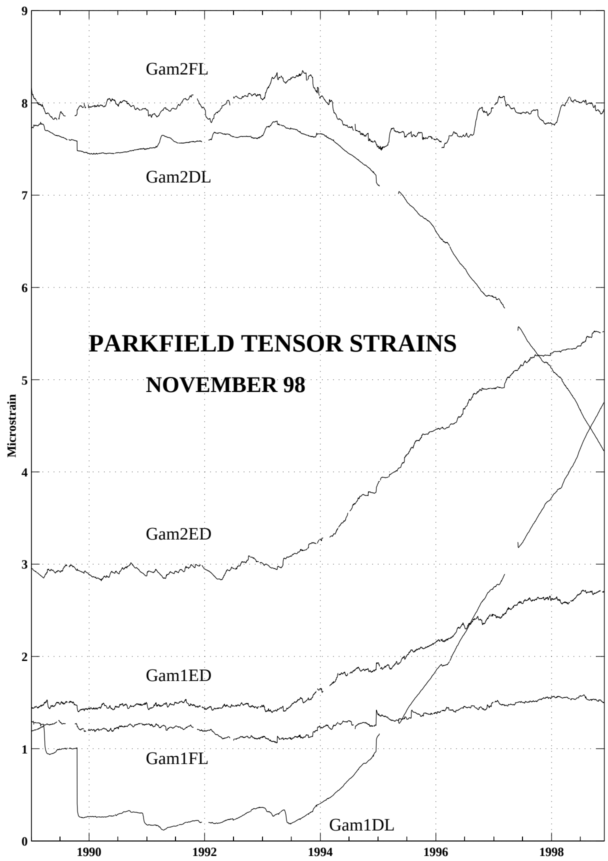

Figure 5. *Strain data observed on BTSM instruments DLT,EDT and FLT near Parkfield.*

Hayward Fault:

Data observed on the sites along the Hayward Fault are shown in Figures 6 and 7. Each of these sites indicates that an annual hydrological influence is present in the areal strain data. This effect is at a level of less than 250 nanostrain in the shear strain data.

In 1996/7, some indication of cable leakage due to damage which occurred 20m from the well head during installation of the Garin instrument cable was noted as capillary moisture at the pit. Repairs were carried out, but there is evidence that cable erosion is continuing. Repairs to the downhole cable are not physically possible. Shear strains at the Chabot site have been remarkably stable over the 5 years of operation.

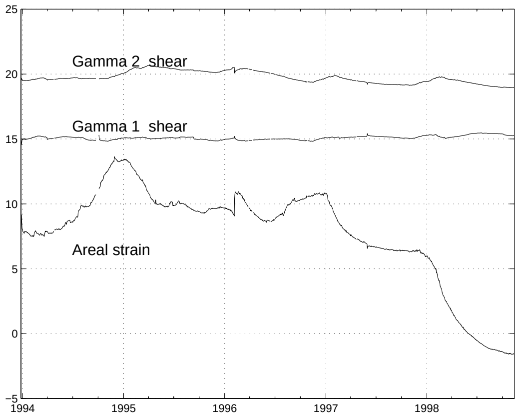

Figure 6 *Strain data from the Chabot site, 5 km from the northern section of the Hayward Fault.*

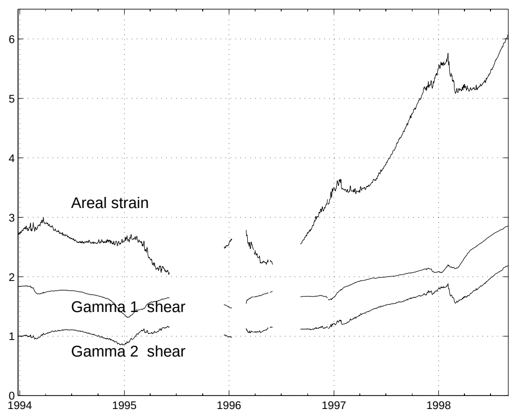

Figure 7 *Strain data oberved at Garin 5 km from the central section of theHayward fault.*

Data Availability

Archived strain data from the Californian sites is stored in both raw component form, and as processed areal and shear strains. A regularly updated archive of data has been maintained in the USGS Menlo Park computer system since 1988. This data is stored in binary files with appended header information (USGS "*bottle*" format).

Data is accessible in *thebeach:/we/mick/BASEDATA*. Automatically processed near-realtime data is available in *thebeach:/we/mick/QUICKCHECK* for users with access to USGS plotting software "*xqp*", and via the USGS crustal deformation web pages in graphical form. Home page for access to all web data from borehole tensor strain instruments is *http://www.dem.csiro.au/~rossg/straincal/straincal.html*

Scientists requiring access to the archived data should contact Dr. R. Gwyther (+617 3212 4586, email*: r.gwyther@cat.csiro.au*) or Dr. M.T. Gladwin (+617 3212 4562).

Publications

Recent Publications 1997-98

Langbein, J., R.L. Gwyther and M.T. Gladwin Possible increase in fault slip rate at Parkfield in 1993 as inferred from deformation measurements from 1986 to 1997 *Seis. Res. Lett*. v69(2), p 151, 1998

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Gladwin M.T., R.L. Gwyther and M.Mee High-Precision Continuous Deformation Monitoring of Mine Structures *Proc. 13th Int. Geophys. Conf*., A.S.E.G., 1998

Gladwin M.T., R.L. Gwyther and R.H.G. Hart. Long-term borehole tensor strain data at Parkfield,CA: Issues of Interpretation *EOS. (Trans. Am. Geo. Un.)* v78(17), p S219, 1997

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Johnston M.J.S., R.Gwyther, R.J. Mueller, A.T. Linde, M.T. Gladwin and G.D. Myren A triggered Slow Earthquake on the San Andreas Fault in April 1996 *EOS. (Trans. Am. Geo. Un.)* v78(17), p S209, 1997

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Gladwin M.T.G., R.L. Gwyther and R. Hart Persistence of Parkfield Shear strain anomaly commencing in 1993-94 *EOS. (Trans. Am. Geo. Un.)* 78(46) , 1997

Selected Previous Journal Publications

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Gwyther R.L., Gladwin M.T. and Hart R.H.G. (1992) A Shear Strain Anomaly Following the Loma Prieta Earthquake. *Nature* Vol 356 No.6365 pp 142-144.

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Gladwin, M. T. and Wolfe, J. Linearity of Capacitance Displacement Transducers. *J.Sc.Instr*. 46, 1099-1100, 1975. .

Non-Technical Summary

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